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Minimizing the environmental effects caused by the production of bioenergy

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ABSTRACT

Obtaining energy through the combustion of biomass proves to be a significant fraction of the total of what has come to be called "renewable energy." Far from stagnating, energy planning at EU level foresees a considerable increase in this energy sector, so that by 2020 it is expected that renewable energies will form up to 20% of total energy production.

Focusing on the bioenergy sector, a problem that may not yet have been sufficiently addressed is the management of waste from the combustion of biomass; however, in the medium to long term it may cause significant effects on the environment, since the majority of it is deposited in landfill sites.

This opens up an interesting field of applied research, focused primarily on developing processes which will allow the recycling of these waste materials by putting them to good use and thus prolonging their useful life. This paper presents the basic lines of research carried out by our team in this field, with positive and negative results that may serve for other teams to open new lines of research or to go in greater depth into those already begun.

Contents

1. Introduction

The use and abuse of natural resources which have been going on since the industrial revolution of the 19th century, and most worryingly in the last decades of the 20th and early 21st centuries, is clearly not a rational, moral or ethical road to follow, and it can no longer be justified or maintained. Citizens and governments, international organizations and associations of all kinds must be made aware that the possibilities for the future of the world and its inhabitants pass inexorably through a radical change in approaches to development and even in individual habits, as stated in Principle 3 of the Rio Declaration: "The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations".

The Brundtland Report, originally and very descriptively entitled "Our Common Future", is the first to mention the term "sustainable development", defining it as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs".

With this in mind, one of the aims is to achieve maximum efficiency in the use of non-renewable resources, primarily of energy, and to find alternative sources based on the advancement of renewable energies as a basic line of R&D. One of the main sources of renewable energy worldwide is so-called "bioenergy", produced

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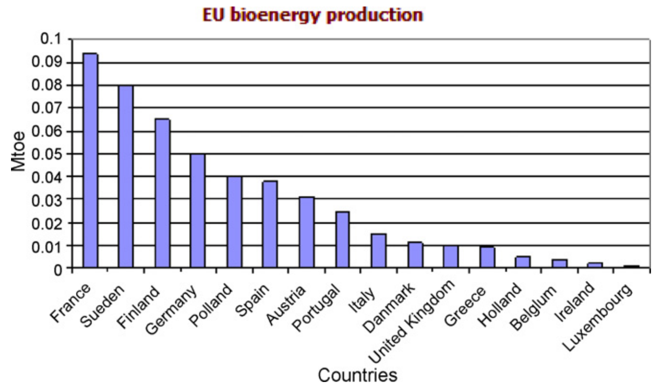

Fig. 1. EU primary energy production from biomass in millions of tons of oil equivalent (Mtoe).

principally by burning biomass, which, as can be seen in Fig. 1 for the EU, shows production levels which are certainly of interest.

However, the objectives of the European Union for 2020 are far more ambitious, insofar as it is intended to produce up to 20% of energy from renewable sources, anticipating that the production from the burning of biomass may contribute 25.4% of the total. Since at present the production of energy from renewable sources is about 6% of total production (Fig. 2), the next few years will see truly spectacular development in the establishment of production facilities from renewable energy sources, and in particular those based on the use of biomass.But against the list of the benefits brought about by the growth of renewable energy must be offset the dangers and inconveniences that may result from its excessive use. Thus, while the report "Global Potential of Biomass for Sustainable Energy" presented by the World Bioenergy Association (WBA) in December 2009 in Copenhagen estimated that by 2050 the estimated potential production of such energy may be between 1135 and 1548 exajoules (EJ) for an estimated energy demand of about 1000 EJ, researchers and scientists are beginning to reflect on the problems that may arise from intensive agricultural production oriented towards the feeding of bioenergy production facilities [1–4]. The UN has issued a number of reports warning of the dangers that may arise from the uncontrolled growth of the use of biomass for energy production: deforestation, increased food prices, etc.

In this search for a balance between benefits and drawbacks, an aspect often overlooked is the management of the waste generated in the production of certain renewable energy sources, and particularly that obtained from the combustion of biomass. The high level of biomass that has to be used for energy production (0.8 kg/kWh) generates a not inconsiderable amount of waste products (slag and ash), a high percentage of which are dumped in landfills. The increase in the production of energy expected from these processes in the coming years will lead to an exponential growth in the volume of waste material – material which may constitute a serious environmental problem.

The research project carried out in our Department of Planning and Agricultural Engineering of the Public University of Navarra has focused on finding alternative uses for some of these waste materials, so that they may be reused in other economic activities, achieving two complementary goals: on the one hand, to avoid the dumping of enormous amounts of waste materials, and on the other to reduce the need for raw materials, which will undoubtedly contribute to the sustainability of the process.

2. Biomass and the waste materials generated by its combustion

Among the number of things which have come to be called renewable energy, we can highlight the bioenergy group, characterized by the provision of processes to obtain the energy contained in "biomass", by which is understood any organic material capable of being used for energy production. Materials such as forestry by-products, agricultural crops, gardening offcuts, agro-industrial by-products or even residues of human or animal origin may be considered as falling within the concept of biomass.

Over the last decade Spain has seen significant developments in the field of alternative energy in general, and in particular in biothermal power-plants, so that there are currently more than 112 fully operational biomass plants. This rapid expansion is due, among other factors, to the fact that the technology used in conventional thermal power plants fired by fossil fuels can be used with slight modifications (mainly of the feed system) for use in the combustion of organic (renewable) matter. This implies an annual production of 5,300,000 MW, which would be the equivalent of that obtained by burning 6,272,800 metric tons of oil. In terms of pollution, the production of bioenergy has meant a decrease in the emission of CO_2 to the atmosphere of 13,300,000 t.

However, the overall situation is not ideal since, as mentioned above, in the process of bioenergy production there is a point which is so far unresolved, at least completely: the generation of waste. If the future of energy lies in the encouragement of production from

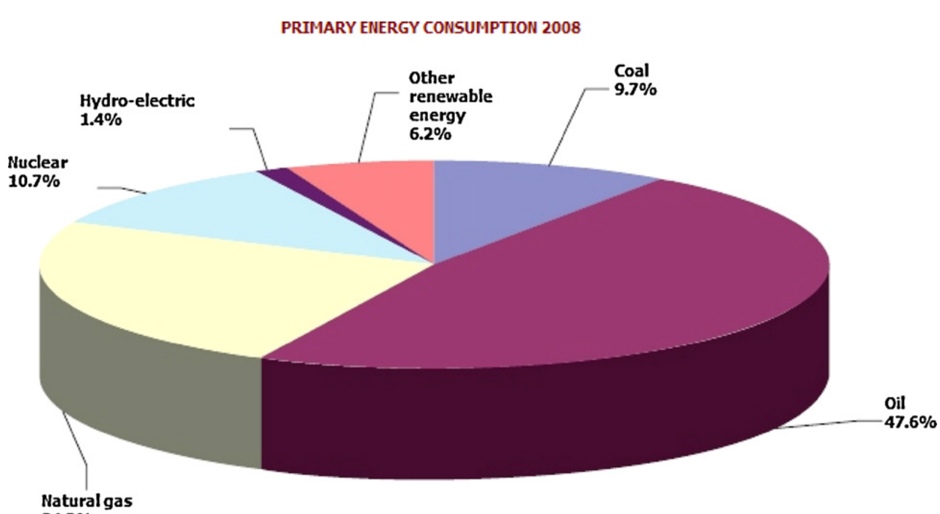

Fig. 2. Percentage of energy production by type.

Table 1
Average % of combustion ash in dry material.

Rape	Straw	Olive oil waste	Thistle	Rice husk
7.70	6.9	4.58	12.31	19.5

renewable sources (and this is the plan at the level of the European Union as a whole and of its member states), power generation by the combustion of biomass will also see a significant increase; and thus the problem of waste generation, treatment and disposal will in itself constitute an environmental problem that will have to be predicted and investigated.

2.1. Waste products of biomass combustion

It is well known that the amount of ash generated during the combustion of biomass varies significantly depending on the material used. Table 1 shows the average percentage of ash in the combustion of dry material of some of the materials most commonly used in these installations.

In view of the performance of such facilities, the most immediate conclusion is that of the significant volume of waste generated. Looking at Spain, an approximate estimate might give results in the following order of magnitude:

Total power generated	5,300,000 MW
Metric tons of biomass used	6,000,000 t
% of ash produced	7–19%
Total waste (weight)	7,000,000 t
Total waste (volume)	5,250,000 m^3

It is true that a percentage of the waste generated is being used for the production of organic fertilizers (such as the remains of cereal straw), but in the absence of concrete data on this point, we believe that such use constitutes a negligible fraction of the total waste generated, which eventually ends up in landfills, and ultimately leads to a considerable negative effect on the environment. This situation gives cause for concern since, far from stabilizing the production of waste, the ambitious agenda of promotion of this type of energy leads to a significant increase of waste products.

3. Approach of the study

The general approach that our research team considered was to close the cycle: indeed, if the use of processes enabling the production of energy through renewable materials generates as a negative result the production of large volumes of waste whose treatment greatly increases the cost of the process, and whose effect on the environment is unquestionable, the approach might be to exploit these waste materials through treatments enabling their recycling in the manufacture of materials suitable for other productive activities: in our case, this second utility was sought in the field of construction and civil engineering. We wish to complement processes and applications enabling a comprehensive use of materials; maximum effectiveness and efficiency.

Our study has yielded results (currently partial), some of which are exciting and some less so. We have focused on two plants that differ in the bio-fuel used: in one case straw (Sangüesa) and the other rice husk (Valencia). In both cases, before starting our study, we sent samples of the material under investigation to the laboratory in order to verify their possible toxicological effects, under the applicable body of law in our country. This legislation, in fact, is the result of the adoption of the European Directives approved on this issue. Table 2 shows a diagram of the tests performed.

Table 2
Tests for toxicity in samples.

Identification by lixiviation in 12457/4	Analytical method	Analytical technique
Antimony	GI/PO/FQT/076 (A.A. Oven)	AA/GFZ
Arsenic	GI/PO/FQT/132 (ICP)	ICP/OES
Barium	GI/PO/FQT/132 (ICP)	ICP/OES
Cadmium	GI/PO/FQT/132 (ICP)	ICP
Chlorides	GI/PO/FQT/118	VOLUM
Copper	GI/PO/FQT/132 (ICP)	ICP
Chromium	GI/PO/FQT/132 (ICP)	ICP
DOC	SM 5310.B	AN. TOC
Phenols	GI/PO/FQT/044 (UV–vis/high interval)	UV–vis
Ph	GI/PO/FQT/024	POTEN
Fluorides	GI/PO/FQT/013 (potentiometry)	POTEN
Mercury	GI/PO/FQT/077 (A.A. Cold vapor)	AA/CV
Molibdenum	SM 3500 Mo/C (ICP)	ICP
Nickel	SM 3500 Ni/C (ICP)	ICP
Lead	GI/PO/FQT/132 (ICP)	ICP
Selenium	GI/PO/FQT/132 (ICP)	ICP
Dissolved solids	SM 2540 B	GRAV
Sulfates	GI/PO/FQT/001	Turb
Zinc	GI/PO/FQT/132 (ICP)	ICP
Acute toxicity on daphnia	GI/PO/FQT/055	–
Identification in residue	Analytical method	Analytical technique
Arsenic	EPA 7060 (Oven)	AA/GFZ
Cadmium	EPA 7131 (Oven)	AA/GFZ
Cobalt	EPA 7200 (FLAME)	AA/F
Copper	EPA 7210 (Flame)	AA/F
Chromium	EPA 7190 (Flame)	AA/F
Mercury	EPA 7471	AA/CV
Nickel	EPA 7520 (Flame)	AA/F
Ph	ISO/DIS 10390	POTEN
Lead	EPA 7420 (Flame)	AA/F
Zinc	EPA 7950 (Flame)	AA/F
Nitrogen kjeldahl	Kjeldahl	Volume
% Humidity	GI/PO/FQT/140	
Total phosphorus	EPA 365.4	UV/Vis
Organic material	ISO 10694 (Calcination)	GRAV
Dermal irritation/corrosion	GI/PO/FQT/051	–
Lixiviation test	GI/PO/FQT/050	–

3.1. Bioenergy plant of Sangüesa (Navarra)

The first phase of the study was conducted in this plant, mainly due to its proximity to the facilities of the University, just 50 km. It has the added interest of being the first experience in Spain of the generation of electricity from biomass coming from cereal straw (see Fig. 3).

Fig. 3. Sangüesa biomass plant (Spain).

In summary we can give the following details of the installation:

Power	25 MW
Raw material used	Cereal or maize straw
Raw material consumption	160,000 t/year
Production	200 GWh/year
CO_2 emissions avoided	200,000 t/year
Waste material generated	9.600 t/year

3.2. Research procedure

As a starting point we decided to study the possibility of using fly ash and slag combustion waste as an additive to stabilize soils. While it is true that previous analysis of the material reported the presence of sulfates, we knew that some researchers in the field [5–7] had already used as soil stabilizers materials with a greater or lesser presence of sulfates. Our main motivation for directing research towards the stabilization of soil was greatly influenced by the proliferation of marl in much of the Autonomous Community of Navarre and in general throughout the north of Spain. The marl on which it was intended to act is a soft rock, gray in color and without defined stratification; its main features are that, on one hand, it is a very changeable material in contact with the environment, and on the other it has a low bearing capacity. This means that in civil engineering and construction work it is necessary either to replace a certain thickness of this soil with another of better mechanical properties, involving major earthworks and subsequent dumping in landfills; or to stabilize them with cement. The opportunity to use the waste from the bioenergy plant as a stabilizer was sufficiently attractive to start work in that direction.

However, the results did not live up to expectations, so that the specimens, cured in a moist chamber, broke spontaneously due to the formation of "ettringite" as a result of the combination of the sulfates with oxides of Ca and Al. This adverse outcome resulted in a reorientation of the work, turning the approach of the research on its head: perhaps it would be possible to obtain a reusable material by a process of stabilization of the waste generated by the process of bioenergy production. In other words, reversing the terms: from stabilizing material to stabilized material.

Following this line, samples have been produced with a composition of 50% slag and cement. So far, the external appearance of the specimens is really good, and resistance results obtained in press have yielded good results. While these early results are encouraging, it is necessary to conduct analysis and monitoring over time in order to obtain data to define the material with sufficient safeguards, and thereafter to select any constructive elements in which it could be reused.

The identification of this stabilized material is being directed mainly towards properties such as its behavior in the presence of water (water resistance, swelling, extent of absorption), resistance to polishing, brittleness, color options, ease of cutting, etc. In other words, looking for a use for it in non-structural building elements which do not require high mechanical strength, such as curbs, tiles, roofing tiles and paving.

3.3. Bioenergy plant of Almassera (Valencia)

This case is interesting from the point of view of how economic interest alone can sometimes coincide with the sustainability approach, so that a problem, with good management, becomes an added input, combining economic profit and environmental benefit.

In the town of Almassera there is a cooperative of rice farmers, an activity that generates a significant residual volume of "husk" which has traditionally been dumped in landfills. In the year 2000, managers of the cooperative studied the possibility of installing a bioenergy plant to use as fuel the waste generated by their activity. The plant, launched in 2002, currently uses an amount in excess of 15,000 metric tons per year of rice husk, obtaining an energy production of 2 MW/year. The percentage of ash is about 19% of the material provided, which means a substantial amount of waste (see Fig. 4).

Fig. 4. Almassera biomass plant (Spain).

3.4. Research procedure

Analysis of ash samples collected indicated that their chemical composition was practically 100% silicon dioxide (SiO_2), which initially augured well in terms of its potential usefulness for soil stabilization. Given the interesting chemical composition of the waste, it was decided to broaden the scope of possible soil types to be stabilized, so that in our laboratory at the University, with the material collected from the Almassera plant, we have been working on three different soil types: marls, expansive clays and sulfate-rich soils. On these soils, usually stabilized with lime, we have investigated different scenarios for stabilization with mixtures of lime and combustion ash, modifying the proportions of each.

The research has monitored the following: simple compressive strength and CBR index of the samples at different stages of curing and the appearance of counterproductive effects in the mixtures of the soils with the additives (expansiveness and workability).

The results have certainly been positive: thus, according to our experiment, we are in a position to state that the improvement in mechanical properties of the treated soils was more effective when stabilization was done solely with ash than when they were mixed with varying percentages of lime (see Figs. 5 and 6).

However, there has still been no process of real achievement, an application to the real world of civil engineering. The steps we have taken so far have encountered difficulties from the two main parties involved: on the one hand, construction companies are wary of the very process itself and of the availability of sufficient stabilizing product at all times; and the company generating the waste sees the situation as the solution of a more pressing problem it has, which is the management of waste products, but now as a material with added value from which it hopes to get a – possibly exaggerated – economic return.

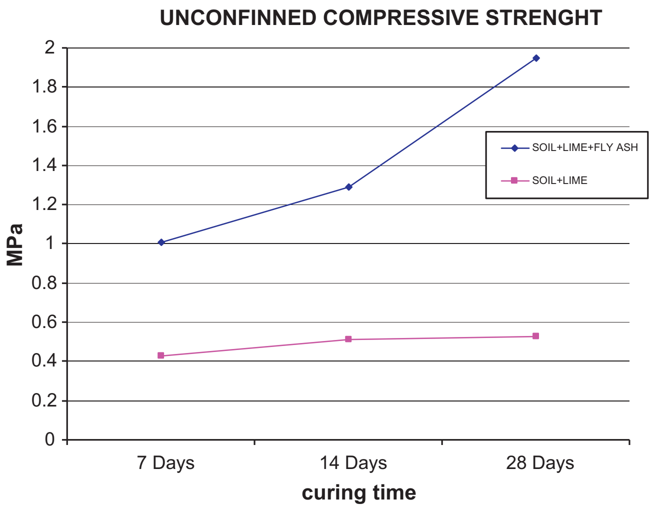

Fig. 5. Results of unconfined compressive strength tests of soil with lime and with rice-husk ash.

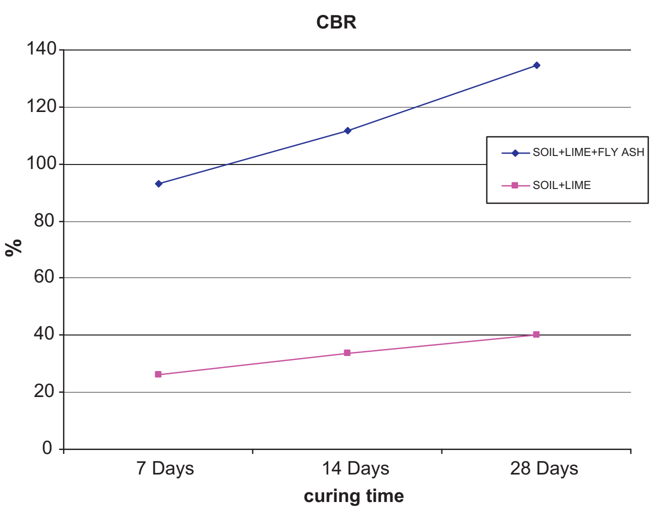

Fig. 6. Results of CBR index of combinations of soil with lime and with rice-husk ash.

This situation may seem beyond the purview of a research project; however, the effectiveness of a research process should be evaluated according to its practical application. Indeed, in our view, scientific knowledge has to leave the laboratory to involve itself in the actual field where it is needed. Only in this way does scientific knowledge act for the benefit of the society that supports it. Knowledge management is essential for research work to manifest itself in tangible results. The pursuit of scientific knowledge should not be an object in itself; scientific discovery acquires meaning when by acting effectively on the real world it somehow, in the short or long term, improves the lifestyle of society.

4. Conclusions

1. An integrated approach to "sustainable development", as regards the production of energy research, must be promoted along two parallel lines: the first is that dealing with research, development and efficiency of new renewable energy sources; the second addresses the full cycle of the process, so that alternative ways can be found for waste products, exploiting them and reusing them in other productive activities.
2. The diversity of scientific knowledge necessary for a comprehensive study calls for the establishment of multidisciplinary scientific teams which, on the basis of research in individual sectors, are able to develop global processes integrating, coordinating and harmonizing fields of specialized knowledge in solutions that address the sustainability of the process as a whole.
3. As regards the optimization of the balance between energy production and economic cost, in the specific case of bioenergy it is particularly necessary to undertake a nationwide study to determine the ideal location for energy production facilities, based on variables such as the need for biomass to obtain the planned production, space needed, and transportation costs. This optimization of location is a conclusive factor in determining the costs of energy generation, and therefore an important factor in the viability of the process.
4. The role of university research teams can be highly appropriate and effective, allowing both the diversification of specialized knowledge of scientists/researchers and a facility for multidisciplinary teams to be formed to deal with problems from different points of view. University research teams also have two strong points: in the first place, their independence; and in the second, the relative ease with which they can share knowledge and experience with similar university groups on a world-wide basis.
5. Scientific research must get out of the laboratory. The applicability of the knowledge generated involves a very important task of knowledge management. In many fields there are too many barriers between the world of research and the business world; too many problems for the effective and massive application of scientific knowledge in the field of economic activity.

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